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V. F. Dubravin, B. I. Dubrovin, and E. M. Karaseva

One of the major tasks of fisheries science is to study the reproductive environment of fish and their survival in the early stages of the life cycle. /123* The results of estimating egg and larvae numbers (based on stock surveys) depends to a great degree, however, on the specific characteristics of their horizontal and vertical distribution. There is an equal liklihood of obtaining overestimates or underestimates of larvae numbers, if there is a drastic unevenness in their distribution. An attempt was made in 1971 to solve some of the methodological problems involved in estimating the numbers of fish larvae, while carrying out a survey of the larvae of autumn-spawning herring in the North Sea.

*Translator's note: The numbers in the right-hand margin refer to the corresponding page in the Russian text.

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METHOD

The primary tool for collecting samples was a KHAI high-speed plankton collector, which was modified with a Gulf-3 device [4] and equipped with a counter for measuring the volume of water that was filtered.

The total catch of the plankton collector was made by an oblique trawl haul from surface to bottom and back, at a ship speed of five knots. The apparatus was outfitted with a device (an IGEK) for measuring the depth of trawl movement, which made it possible to constantly monitor the apparatus all the way to the bottom and to bring the depth of submergence to 2m from the bottom. The trawling was performed in a straight line, which has two advantages over trawling by circling: (1) the ship can maintain a constant speed and, consequently, the particular depth to which the apparatus is submerged can be maintained during horizontal trawling; and (2) the volume of water filtered is increased due to the fact that there is no angle between the direction of the current and the longitudinal axis of the apparatus.

We used the KHAI to carry out observations on the vertical distribution of larvae. In order to do this, we carried out six series of horizontal trawls with the plankton collector on October 6 and October 7, 1971 at coordinates $54^{\circ}32'$N. and $00^{\circ}22'$E. The trawling was carried out at a depth of 67 to 70 m at the following levels: (1) 10 m level (the 5 to 15 m layer); (2) 35 m level (the 30 to 40 m layer); (3) 50 m level (the 45 to 55 m layer); and (4) 60 m level (the 55 to 65 m layer). During each trawl, the plankton collector made its catch over a vertical distance of 10 m, because the span of deviation between the assigned level and the level over which the catch was actually made was approximately

five meters. As a result, only the discontinuity layer, which was located between 15 and 30 m on average, was not included. The plankton collector remained at each assigned level for a period of 20 minutes, so that each series of trawls usually lasted two hours. A total haul of the bottom - surface layer was made at the conclusion of each series. Since a certain portion of the larvae was caught in the process of lowering and raising the KHAI, the following corrections have been made to the number of larvze in the two lowermost levels: (a) the number of larvae in the bottom - surface layer that was obtained during the total haul was subtracted from the quantity of larvae in the bottom-most level; and (b) the quantity of larvae in the 45 to 55 m level was reduced in proportion to the amount of time lost in lowering and raising the KHAI through the overlying layers of water and in proportion to the number of larvae in them.

The number of larvae at the 10 m and 35 m levels was left unchanged in view of the insignificant quantity of larvae in the overlying layers. In calculating the percentage content at a particular level against 100 per cent, the sum of the corrected number of larvae was taken for all levels for each individual series of trawls. /124

MATERIAL AND RESULTS

In conducting the survey operations at the spawning grounds of the North Sea herring, the distance between the buoy stations amounted for the most part to 10 miles, but to 3 to 5 miles in areas with maximum larvae concentration. The results showed that the distribution of the larvae is characterized by considerable spottiness, which is particularly noticeable in the case of small larvae with a length of less than 10 mm.

The diameter of these spots varies from 3 to 5 miles to up to 10 to 15 miles. The existence of this spottiness is easily judged from Figure 1, which shows the variation in the number of larvae over six hours at one and the same location. This variation was caused by the currents, which transported the larvae. If we calculate the current velocity at approximately 50 cm per second, then the quantity of larvae can change tenfold over a distance of 4 to 6 miles. It follows from this that the distance between stations is of considerable importance in estimating larvae numbers. We conducted the following statistical experiment in order to solve the problem of selecting the optimum distance between stations.

We assumed that the average number of larvae under one square meter of the testing area in the spawning grounds, which had a surface area of 20 x 40 miles, is equal to the mean arithmatic value of all observations. This assumption was based on the fact that the distance between the stations in the testing area was 3 to 5 miles, while their total number amounted to 35 to 40. The testing area was divided into two parts, from each of which we selected one station by using a table of random numbers. The mean of these two stations was taken as the mean number of larvae in the testing area. This operation was repeated 100 times.

The next step was to calculate the standard deviation of the mean value of the number of larvae that was obtained from the two stations from the mean value that was obtained from the total data from all stations in the testing area. The ratio between the standard deviation and the true mean value was used to estimate the accuracy of the value obtained for the number of larvae from the two stations in the testing area. Since we know the dimensions of the testing area, it is an easy matter to pass from the number of stations to the distance between them.

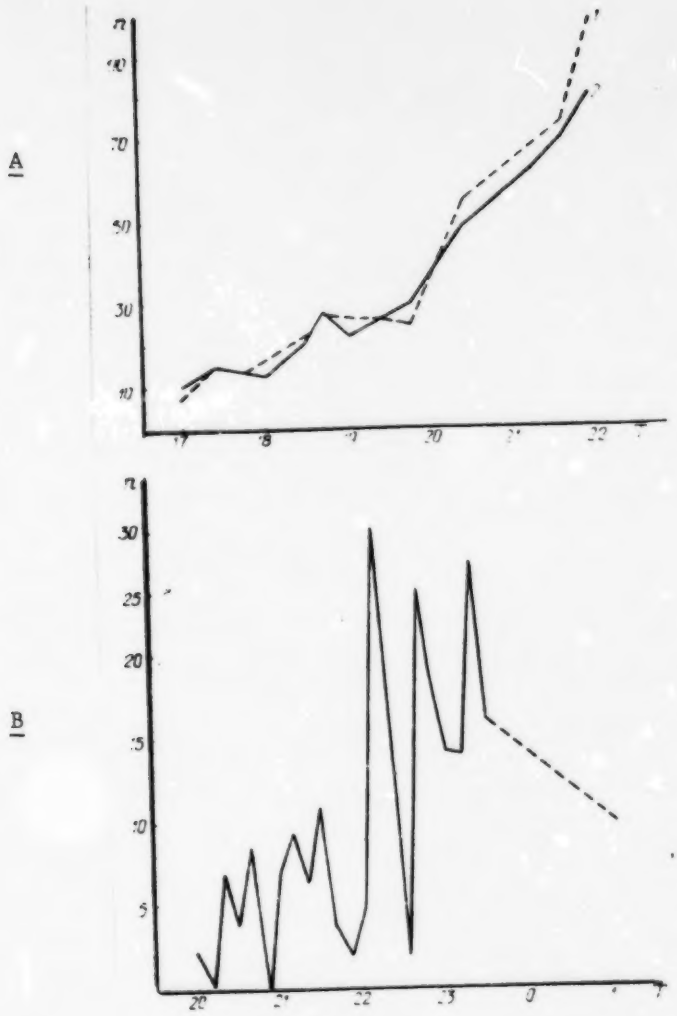

FIGURE 1

The variation in the number of herring larvae in the surface - bottom layer at the buoy station (54°38'N. and 00°10'E.):

A - KHAI, September 30, 1971; 1 - the calculation according to the meter for measuring the volume filtered; 2 - the calculation according to the log references;

B - Grid Station 80, October 1, 1971; n - the number of larvae; t - the time in hours.

Accuracy was treated in the same manner in obtaining the mean characteristics for 4, 8, and 16 stations.

Calculations were made from three testing areas and then they were averaged. It follows from the results that were obtained that in order to obtain a 25 per cent accuracy, the distance between the stations should not exceed 7 miles (Figure 2, A).

A similar procedure was used to estimate the accuracy in determining the average water temperature (surface and benthic) and the biomass /125
of the seston [plankton plus tripton]. It is worth noting that the distribution of the benthic temperature shows considerable spottiness, as a result of which the benthic temperature must be recorded somewhat more frequently than the surface temperature in order to obtain the same de- /126
gree of accuracy (Figure 2, B).

The results of vertical trawling uncovered considerable unevenness in the vertical distribution of the larvae, the distribution changing as the herring larvae attained a certain size. Consequently, all of the larvae were divided into two size groups; the first group included larvae with a length of 6 to 12 mm; the second, larvae with a length of 13 to 21 mm.

The distribution of the small herring larvae is characterized by the fact that the bulk of the larvae (up to 55 per cent) were located during the course of the day under the discontinuity layer at the 35 m level. Their numbers decreased successively in the lowerlying layers. For the greater part of the day the number of larvae at the 10 m level remained in the order of 10 to 12 per cent (in Figure 3, A the percentage content of larvae is given without the 10 m level). The distribution of larvae at every level was characterized by rather considerable variations in numbers during the course of the day, caused by the transport

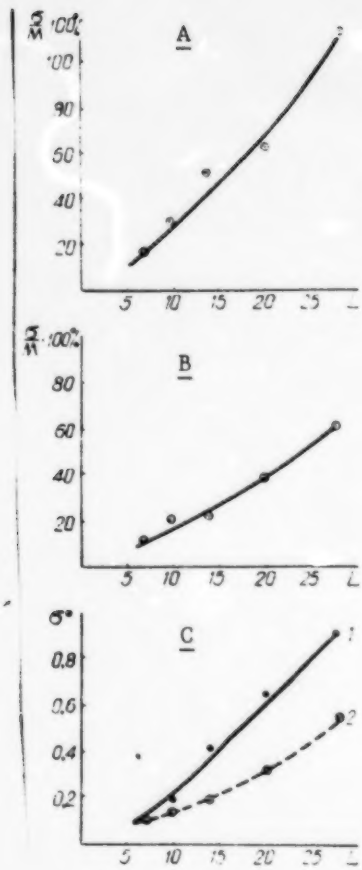

FIGURE 2

An evaluation of the accuracy in determining the average values of the number of larvae, the biomass of seston, and the water temperature in the spawning grounds of herring in the North Sea, as a function of the distance between stations:

A - herring larvae;

B - seston biomass;

C - water temperature:

1 - benthic water temperature;

2 - surface water temperature;

L - distance in miles;

σ - standard deviation; and,

M - average value.

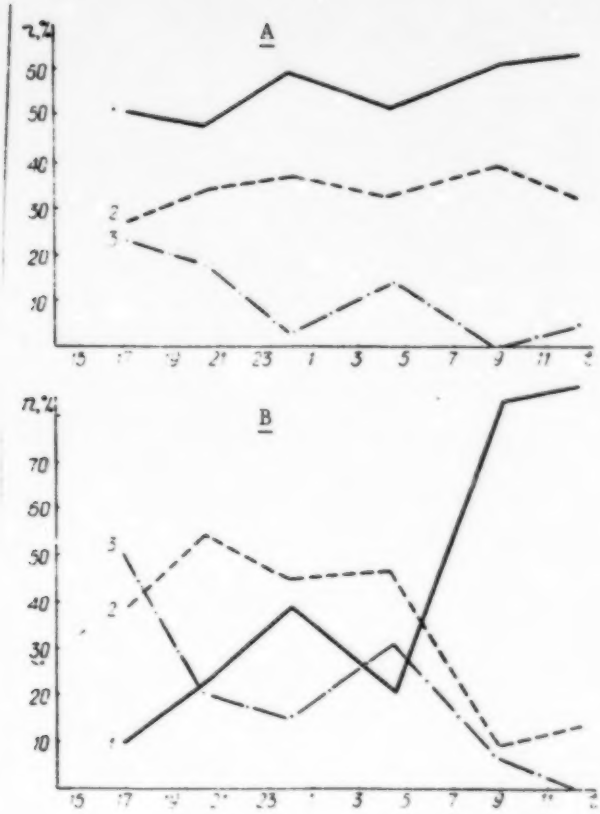

FIGURE 3

The vertical distribution of herring larvae in the bottom - thermocline layer:

A - larvae 6 to 12 mm long;

B - larvae 13 to 22 mm long;

n - the quantity of larvae, %;

t - the time in hours;

1 - the 35 m level;

2 - the 50 m level; and,

3 - the 60 m level.

of larvae stocks by the currents.

These variations were coincident (with some deviations), which is especially clear for the 35 m and the 45 m levels, where the increase or decrease at one level corresponds to a like change at the other level (Figure 4).

The predominance of small larvae at one and the same level during the course of the day and the simultaneous occurrence of variations in their absolute numbers at the different levels confirm the absence of any significant vertical displacements among them. If, however, we express the number of larvae at the different levels as a percentage in order to eliminate the effect of spatial discontinuity (see Figure 3, A), /127
we then observe a certain tendency towards an inverse change in the number of larvae at the 35 m level in comparison with the 50 m and 60 m levels; in other words, vertical displacements of small scale are, in fact, observed among the small larvae.

The vertical distribution of the large larvae is characterized by the existence of significantly large vertical displacements (Figure 5 and Figure 3, B). At 1700 hours the number of larvae was at its peak in the near-bottom level and decreased moving from bottom to surface; 90 per cent of all the large larvae were situated within a layer of 20 m at the bottom and only 8 percent were under the discontinuity layer. Then the number of larvae began to increase at the 45 m and 35 m levels /128
and to decrease at the level near the bottom. This process of upward movement continued until midnight, after which a slight downward movement of the larvae was noticed. But at roughly between 0500 and 0900 hours in the morning their numbers increase sharply directly under the discontinuity layer, while falling sharply at the two lower levels. At

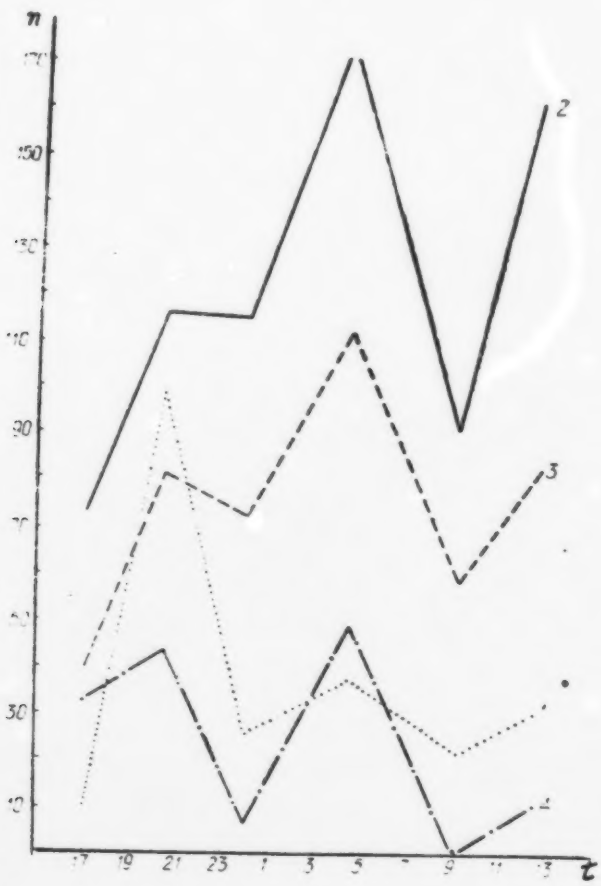

FIGURE 4

The vertical distribution of herring larvae with a length of 6 to 12 mm on October 6 and October 7, 1971:

1 - the 10 m level;

2 - the 35 m level;

3 - the 50 m level;

4 - the 60 m level;

n - the number of larvae; and,

t - the time in hours.

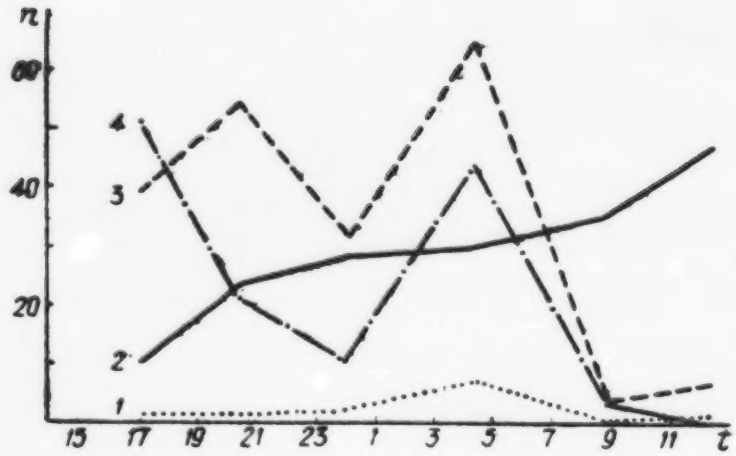

FIGURE 5

The vertical distribution of herring larvae with a length of 13 to 21 mm on October 6 and October 7, 1971:

1 - the 10 m level;

2 - the 35 m level;

3 - the 50 m level; and,

4 - the 60 m level.

any rate, by 1300 hours more than 80 per cent of the larvae were located under the discontinuity layer.

Thus, twice a day we observed periods of upward larval movement (the first before sunset and the second before sunrise), and twice in /129
the day we observed periods of downward larval movement (in the second half of the night and in the second half of the day). The scale of the displacements that were observed amounted to 40 m, allowing us to speak of vertical migrations of the large herring larvae.

We are also able to observe similar periods of upward and downward movement among the small larvae, but the scale of their displacements is considerably smaller. The collected data agrees to a certain extent with the results of R. J. Wood [5], who found that a stratification of the larvae was observed during the day, the largest larvae being the most numerous in the upper and intermediate layers, while the larvae were more evenly distributed throughout the water layers during the night.

Based on our material, the greatest stratification of the large larvae was observed between 0900 and 1230 hours, where they were concentrated under the discontinuity layer, and at 1700 hours, when they dominated the near-bottom layer. At night, the large larvae were more evenly distributed throughout the layers of water.

There can be no doubt that the different scale of vertical displacements shown by the large and small larvae are related to the difference in the extent of their body development, since the studies of S. G. Kryzhanovskii have shown that the locomotive function of herring larvae depends on body size and on the degree of fin development. It is possible that the presence around the clock of the small larvae under the discontinuity layer at the 35 m level is due to the existence of favorable

feeding conditions at that location, since the plankton on which they feed are frequently concentrated under the discontinuity layer [2]. It is of interest to note that the periods of upward movement of the large larvae to the 35 m level coincide with the peaks in the daily feeding pattern of North Sea herring larvae - which occur in the morning and evening hours, respectively, according to Bhattacharija's data [3]. /130 Nevertheless, a comprehensive investigation of the vertical movement of the larvae and of the abiotic and biotic factors in their environment is required for a detailed study of this problem.

The fact that the vertical distribution of large larvae changes during the course of the day must, undoubtedly, have an effect on their representation in the total catch. Let us look at how the number of larvae in horizontal hauls from four trawls compares with their number in the total catch at the very same station. It is clear that this relationship will vary within considerably larger limits in the case of the large larvae than will be the case with the small larvae. We find, in fact, that the difference between catches in horizontal trawling and in total is considerably greater for the large larvae during hours of daylight than during hours of darkness (refer to the table).

Time, hours	The ratio between the number of larvae in horizontal catches and the number of larvae in the total catch		The percentage of large larvae in the total content of catches	
	6 to 12 mm	13 to 21 mm	horizontal catch	total catch
1700	4.6	17.0	39.7	12.2
2020	4.1	7.6	22.5	13.5
0000	2.4	3.2	25.0	20.2
0430	6.2	9.7	28.3	20.0
0900	2.7	42.0	19.8	1.5
1225	5.6	19.0	16.8	5.5

We obtained this very same result when we compared the percentage content of large larvae in horizontal hauls from a total of four trawls with their percentage content in the total catch. The minimum divergence was observed at three stations in the hours of darkness, when the vertical distribution of the larvae was more uniform. The maximum divergence came about in periods when the greatest stratification of larvae was seen to occur, namely (a) at 1700 hours, when most of the larvae were at the bottom, and (b) in the morning, at 0900 and 1200 hours, when most of the larvae were at the 35 m level.

Since one and the same trapping apparatus was used in both types of trawling, horizontal and total, the daily contraction of the proportion of large larvae in the total catches was not because the larvae evaded the plankton collector in the daylight hours, especially since the highest percentage content of large herring larvae in horizontal catches was observed at 1700 hours, before sunset. It is clear that the /131
concentration of larvae in a particular layer can lead to an underestimation of their number in the total catch, while a more accurate estimate of their numbers can be obtained when the distribution of larvae in the water layers is more even.

CONCLUSIONS

1. Considerable spottiness was noted in the horizontal distribution of larvae, as a result of which the choice of a distance between stations comes to have great importance in estimating larvae numbers. An evaluation was made of the accuracy obtained in determining the total number of larvae, the average water temperature, and the seston biomass. Graphs are given to facilitate the estimation of the accuracy of gathered data in relation to the distance between stations.

2. While studying the vertical distribution of the larvae, it was found that larvae with a length of 6 to 12 mm concentrate around the clock under the discontinuity layer at the 35 m level. Larvae with a length of 13 to 21 mm perform very marked vertical migrations, with two periods of movement upward under the discontinuity layer: (a) after sunset, and (b) before sunrise.

3. The daily variations in the vertical distribution of the large larvae is reflected in the fishing efficiency [the ratio of the number of fish caught to the number present in the area fished - **Tr.**] of total trawling. The concentration of the larvae in a particular layer will cause a reduction of their number in the total catch, while a more correct estimation of their numbers can be obtained when the distribution of the larvae in the water layers is more uniform. Stepped fishing will probably be more sound than simple total fishing.

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